NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

HIGH SPEED MARINE CRAFT THREAT: BUOYANCY AND STABILITY REQUIREMENTS FOR A SUB-LAUNCHED WEAPON SYSTEM by John L. Lowery December 1999 Thesis Advisor: Xavier K. Maruyama Second Reader: John D. Babb

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE December 1999	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE HIGH SPEED MARINE CRAFT THREAT: BUOYANCY AND STABILITY REQUIREMENTS FOR A SUB-LAUNCHED WEAPON SYSTEM	5. FUNDING NUMBERS
6. AUTHOR(S) Lowery, John L.	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Military intelligence has considered various coastal scenarios in which the submarine is the only platform available to engage waterborne infiltration forces. Torpedoes are meant for large ships, and cruise missiles are strategic weapons not to be wasted on small craft. Therefore, the submarine does not have a weapons capability to engage and destroy high-speed marine craft (HSMC) that would be used for coastal infiltration.

The most practical scenario would utilize a torpedo stow for a weapon system that would be tube launched, thus ensuring the maximum cruise missile capability of the submarine with a minimal sacrifice to anti-surface and anti-submarine warfare capabilities. The maintaining of the submarine's stealth will be paramount, therefore, an off-hull launcher is desired. The weapon needs to be highly discriminative due to high shipping traffic in coastal waters. In all, the major factors associated with the design and employment of a sub-launched weapon system for engaging HSMC are the threat, the missile, the launcher and the deployment method.

In a hostile coastal environment, there are numerous targets ranging from surface threats to air threats. Missile design is dependent on the threat and can be varied for different scenarios. However, the launcher and deployment of a tube launched weapon system are only restricted by the dimensions of the torpedo tube and the buoyancy and stability of the designed system. These parameters can be quantified and modeled. This thesis focused on designing a weapon system, SEABAT, to meet the basic buoyancy and stability requirements. The results of the SEABAT design prove its feasibility as a torpedo tube launched weapon system.

14. SUBJECT TERMS High speed marine craft, buoyancy, stability, submarine launched weapon system	15. NUMBER OF PAGES 61
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

i

THIS PAGE INTENTIONALLY LEFT BLANK

HIGH SPEED MARINE CRAFT THREAT: BUOYANCY AND STABILITY REQUIREMENTS FOR A SUB-LAUNCHED WEAPON SYSTEM

John L. Lowery
Lieutenant, United States Navy
B.S., United States Naval Academy, 1993

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN APPLIED PHYSICS

from the

**NAVAL POSTGRADUATE SCHOOL**
December 1999
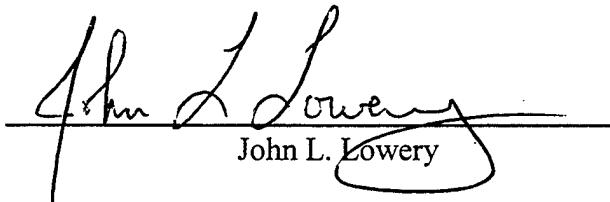
Author: _____
John L. Lowery
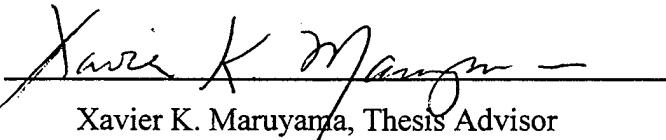
Approved by: _____
Xavier K. Maruyama, Thesis Advisor
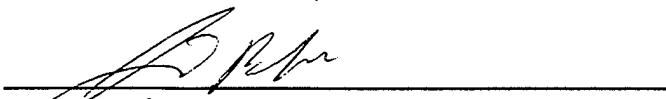
_____
John D. Babb, Second Reader
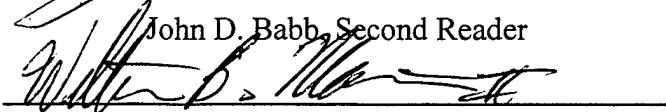
_____
William B. Maier II, Chairman
Department of Physics

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF SYMBOLS[*]

π	"pi" = 3.1452
ρ_a	Density of Air
ρ_{ac}	Density of Anchor Cable
ρ_{sw}	Density of Seawater
ω_o	Oscillating frequency of SEABAT
A_o	Maximum height of SEABAT oscillation
A_a	Cross-sectional area of the anchor
A_c	Cross-sectional area of the canister
A_s	Cross-sectional area of SEABAT
b	Coefficient of the wave equation
BAT	Brilliant Anti-tank Submunition
B_a	Buoyancy of the anchor
B_c	Buoyancy of the cable
B_{se}	Buoyancy of SEABAT at Equilibrium
B_{sl}	Buoyancy of SEABAT at Launch
COB	Center of Buoyancy
COM	Center of Mass
C_D	Drag coefficient
F_D	Force exerted downward on SEABAT
F_g	Gravitational force
F_{g1}	Gravitational force acting on the anchor
F_{g2}	Gravitational force acting on the cable
g	Gravity
HSMC	High Speed Marine Craft
INS	Inertial Navigation System
K	Spring constant
KE	Kinetic energy
L_{ac}	Length of Anchor Cable
L_b	Length of SEABAT Base
L_c	Length of SEABAT Cap
L_{ca}	Length of canister
L_m	Length of SEABAT Magazine
L_s	Length of SEABAT[+]
M	Integer Multiplier for Flooded Anchor Base
m_a	Mass of Anchor
m_{ac}	Mass of Anchor Cable
m_c	Mass of SEABAT Cap
m_{ca}	Mass of One Canister
m_f	Mass force
m_m	Mass of One Missile

---

[*] All units are expressed in this thesis are those common to the Naval Weapons engineering community. Consequently, both English and metric units are used as appropriate.
[+] This symbol refers to the effective length of SEABAT for the purpose of volume calculations as the cap is blown, the base is flooded and the tubes are flooded.

m_{misc}	Mass of SEABAT shell and electronics
m_s	Mass of SEABAT
m_{s2}	Mass of SEABAT after cap is blown
m_{s3}	Mass of SEABAT after anchor is deployed
m_{s4}	Mass of SEABAT after 1st missile launch
m_{s5}	Mass of SEABAT after 2nd missile launch
m_{s6}	Mass of SEABAT after 3rd missile launch
m_{s7}	Mass of SEABAT after 4th missile launch
m_{s8}	Mass of SEABAT after 5th missile launch
m_{sp}	Perceived mass of SEABAT
m_w	Mass of Winch
N	Integer Multiplier for Number of Missiles Launched
NUWC	Naval Undersea Warfare Center
RAM	Rolling Airframe Missile.
r_{ac}	Radius of Anchor Cable
r_c	Radius of canister
r_s	Radius of SEABAT
SEABAT	Proposed Missile Launcher Design
SSN	Nuclear Attack Submarine
t_s	Settling time of oscillation
UVLDS	Underwater Vehicle Launch Dynamics Simulation
V_c	Volume of SEABAT Cap
v_d	Anchor descent velocity
V_m	Volume of SEABAT Magazine
V_b	Volume of SEABAT Base
V_s	Volume of SEABAT
v_s	Initial velocity of oscillation
V_{sa}	Volume of SEABAT Above Water
V_{sb}	Volume of SEABAT Below Water
y_e	Equilibrium Height

ACKNOWLEDGEMENT

I.   INTRODUCTION

The navy of the future will need to master the art of littoral warfare. It is easier for smaller less economically stable countries to establish a fleet of small high, speed marine craft (HSMC) than support a fleet of large combatants. Controlling coastal regions and "chokepoints" are vital to shipping and trade as well as maintaining a peaceful presence in areas of unrest. With the downsizing of the United States Navy, it has become more difficult to provide a naval presence in every hostile region around the world. It has become necessary for naval platforms, that were designed mission specific, to become multidimensional. No longer will we be provided the availability of numerous platforms in a rapid response for all scenarios, but rather we must provide the existing platforms with the technology to engage multiple scenarios with the highest success rate probability [Ref. 1].

HSMC is a general term that refers to craft of patrol boat and hovercraft size that can reach speeds in excess of 40 knots. They have highly versatile weapons' capability ranging from surface-to-air missiles, surface-to-surface missiles, torpedoes, five-inch guns and small arms. Their missions range from coastal patrol to troop insertions. Any conflicts with HSMC would be ideally engaged with air and surface assets but unfortunately they are not always available for rapid response. The HSMC provides aggressor countries the ability to strike quickly in coastal zones with little or no warning. In many instances the attack submarine (SSN) is the only available platform to provide rapid response of an impending HSMC coastal insertion and attack. However, the SSN has no means to engage HSMC but can only monitor their movements. In the past surveillance alone would have been sufficient because other platforms would be readily

1

available to engage the threat, but in today's world we are not afforded that luxury and immediate action is required from the SSN. A solution to address this challenge may be to provide the SSN with the weapons capability to engage HSMC to potentially repel or slow down the attack until other assets can be brought on station.

Any submarine weapon system design must not hinder the submarine's movement and stealth qualities. An off-hull launcher would be ideal to maintain submarine stealth, especially in shallow water. The easiest way to deploy such a launcher would be by use of the torpedo tubes. If it could be shown that buoyancy and stability constraints based on torpedo tube dimensions could be overcome then such a weapon system would be feasible.

This thesis investigates the feasibility of a submarine launched weapon capable of responding to an immediate HSMC threat. The conclusion reached in this study is that, from considerations of physical feasibility, a submarine launched weapon is capable of such a mission. Economic, operational and political considerations have not been fully investigated in this study.

II.   WEAPON SELECTION

A. REQUIREMENTS

Every weapon is defined for a specific purpose, and the constraints associated with the weapon's purpose establish the guidelines for the weapon's design. For this scenario, the SSN is in close proximity to the threat and in relatively shallow, littoral waters. Friendly assets are not readily available and coastal shipping traffic is high. The threat has the ability to travel in excess of 40 knots and has the potential to engage the SSN with torpedoes.

1. Environmental

Coastal regions, by definition, are in close proximity to land. Therefore, to engage HSMC in the littoral zone, the missile need not have an excessively long range. By examining coastal regions around the world one can surmise that the shallow water contour line (30 fathoms) varies in distance from the shore but rarely exceeds 10 nautical miles [Ref. 1]. Therefore, a missile used to engage HSMC within the coastal region would be effective with a 10 nautical mile range. That would cover a circular region of radius 10 nautical miles from the launch point of the missile.
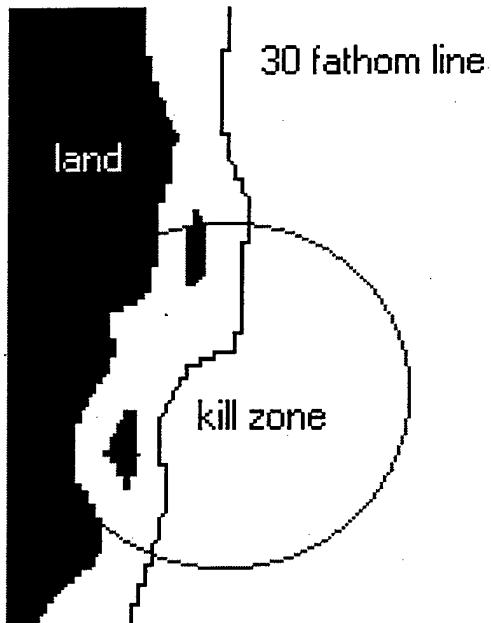
Figure 1. Coastal Region. This is an example of a potential coastal region including the 30 fathom contour line. The kill zone represents a circular area 10 nautical miles in radius centered on the launcher position where the proposed weapon system could engage the enemy.

Coastal regions are normally host to large shipping and traffic zones. Therefore, the missile must be highly discriminative in order to target hostile craft only. The environment imposes a range and discrimination requirement to combat the HSMC in the littoral zone.

2. Submarine

Because submarines are limited in available space, the inception of a new weapon system must maximize the use of the existing configuration of the submarine. Torpedo tubes provide the ideal launch vehicle for the weapon and torpedo stows[1] provide the ideal storage space. The tube and stow are dimension matched for torpedoes. Consequently, a weapon system that fits into the stow will typically fit into the launch

---

[1] A stow is the shelf where a submarine stores its torpedoes.

4

tube. Stows measure 248.5" long by 21". The weapon must not exceed these dimensions to be compatible with the existing configuration. There is also a maximum weight limit of 4600 lbs for each stow.

The submarine has been a very effective platform, primarily due to its inherent stealth qualities. To protect the stealth of the submarine, an off-hull launcher is proposed for the weapon system. The submarine will be within visual range, in some instances, of the threat and any submarine launched missile will be seen when it broaches the surface, thus revealing the submarine's location.
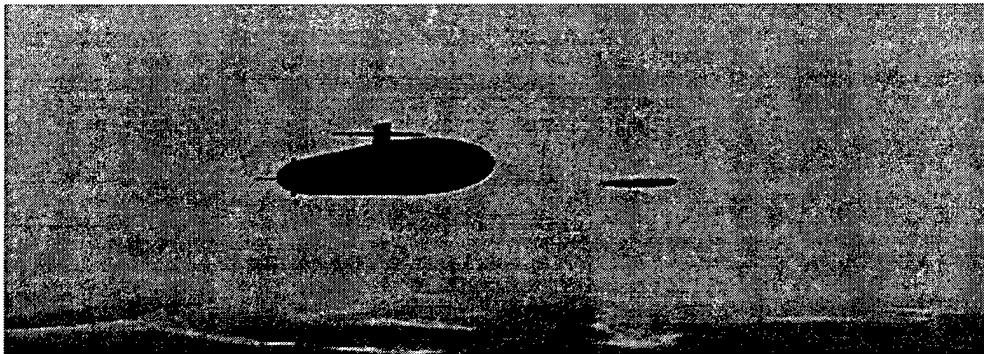
Figure 2. From Ref. [2]. Submarine Launch. Example of a submarine launching the proposed weapon system from its torpedo tube while still maintaining stealth.

With an off-hull launcher, the submarine is still somewhat restricted to maneuver by the shallow water. Consequently, for the submarine to be free to maneuver and engage throughout the attack, the missile needs to be "launch and leave". All the submarine has to do is launch the off-hull launcher, identify the threat and fire the missile. There will be no need to follow the missile throughout its flight to insure the target is hit. In all, the submarine imposes a size limit on the launcher, a need for off-hull launch and "launch and leave" targeting for the missile.

B. SELECTION

The current inventory of missiles for which the United States has access is extensive with numerous shapes, sizes and capabilities [Ref. 3]. For a weapon system to be viable, it must be cost effective. The weapon should not be more costly than the platform we are engaging. The design should include the ability to engage multiple targets because the coastal threat scenarios include multiple HSMC. A multiple missile launcher seems most appropriate and effective. It would also provide more capability within the limited storage space on a submarine. With that in mind, the dimension restrictions for the weapon system will provide a five-missile launcher and two launchers per stow. To fit within the submarine stow constraints, the maximum length will be 123" and maximum diameter will be 6" for each missile. In order to shorten development time and cost, several currently available missiles were reviewed to identify compatibility with the aforementioned requirement. No existing missile meets all the requirements as defined by the environmental and platform constraints. However, there are two weapons that provide the most compatibility for a potential combination of existing missiles.

The first missile considered is the Rolling Airframe Missile (RAM) [Ref. 3]. The RAM is an AIM-9 Sidewinder with a smaller diameter due to reduced fins that are folded into the body while in the launcher. Spinning the missile's airframe in flight compensates for the loss of fin area and accounts for the name, rolling airframe. The RAM has a very particular guidance and tracking package that is not capable of a horizontal launch and the warhead is not powerful enough to provide significant damage to a HSMC. However, the booster provides the necessary propulsion to achieve the desired ranges.

MISSILE	FAILURE CRITERIA
AIM-7 Sparrow	- Exceeds max diameter
AIM-9 Sidewinder	- Exceeds max diameter
AIM-54 Phoenix	- Exceeds max diameter
AIM-120 AMRAAM	- Exceeds max diameter
AGM-45 Shrike	- Exceeds max diameter
AGM-65 Maverick	- Exceeds max diameter
AGM-84 Harpoon	- Exceeds max length and diameter
AGM-86 ALCM	- Exceeds max length and diameter
AGM-88 HARM	- Exceeds max length and diameter
AGM-114 Hellfire	- Insufficient range, exceeds max diameter
AGM-122 Sidearm	- Exceeds max diameter
AGM-123 Skipper II	- Exceeds max length and diameter
AGM-130	- Exceeds max length and diameter
AGM-142 Have Nap	- Exceeds max length and diameter
BGM-71 TOW	- Insufficient range
BGM-109 Tomahawk	- Exceeds max length and diameter
FIM-92 Stinger	- Insufficient range
Rim-67 SM-2	- Exceeds max length and diameter

Table 1. From Ref. [3]. Missiles Reviewed and Failure Criteria. Each of these missiles has some potential for incorporation into the submarine deployed weapon system but has a critical physical shortcoming.

The second weapon, that will provide the warhead and seeker, is the Brilliant Anti-Tank Submunition (BAT). The BAT [Ref. 4] weighs 44 lbs and measures 35.9" long. It easily meets the diameter restrictions. BAT was developed as a submunition contained in aircraft missiles designed to engage tanks in the battlefield environment. It has a very discriminating sensor that switches from acoustic to infrared sensing prior to impact. The booster from RAM and a generic, inertial navigation system will provide the BAT with its initial altitude and point of release over the targets. BATs' own acoustic and infrared tracking system will take care of the rest.

Figure 3. From Ref. [5]. Brilliant Anti-Tank Submunition. The BAT has four "arms" with acoustic sensors at the end of each one to listen for the target as it glides in for the kill.

Once BAT achieves altitude it deploys a parachute to glide down on the target area. It uses its acoustic sensors at the end of each of four "arms" to initially acquire and guide into the target. It then releases its parachute and free falls toward the acoustic signal. A second parachute is deployed to provide time to more accurately pinpoint the acoustic signal. It then releases the second parachute and glides into the target with an infrared seeker. A couple potential problems arise with the employment of the BAT. First, the BAT must be fired soon enough to provide sufficient glide time down on the target area before the targets leave the "kill zone", and most importantly, the BAT must be provided the acoustical data on the targets to accurately discriminate them from friendly and neutral shipping. However, the BAT provides a very formidable warhead and discriminating seeker that with the booster from the RAM provides a capable, relatively inexpensive solution to the problem. All that is needed is a launcher capable of housing and firing such a missile.
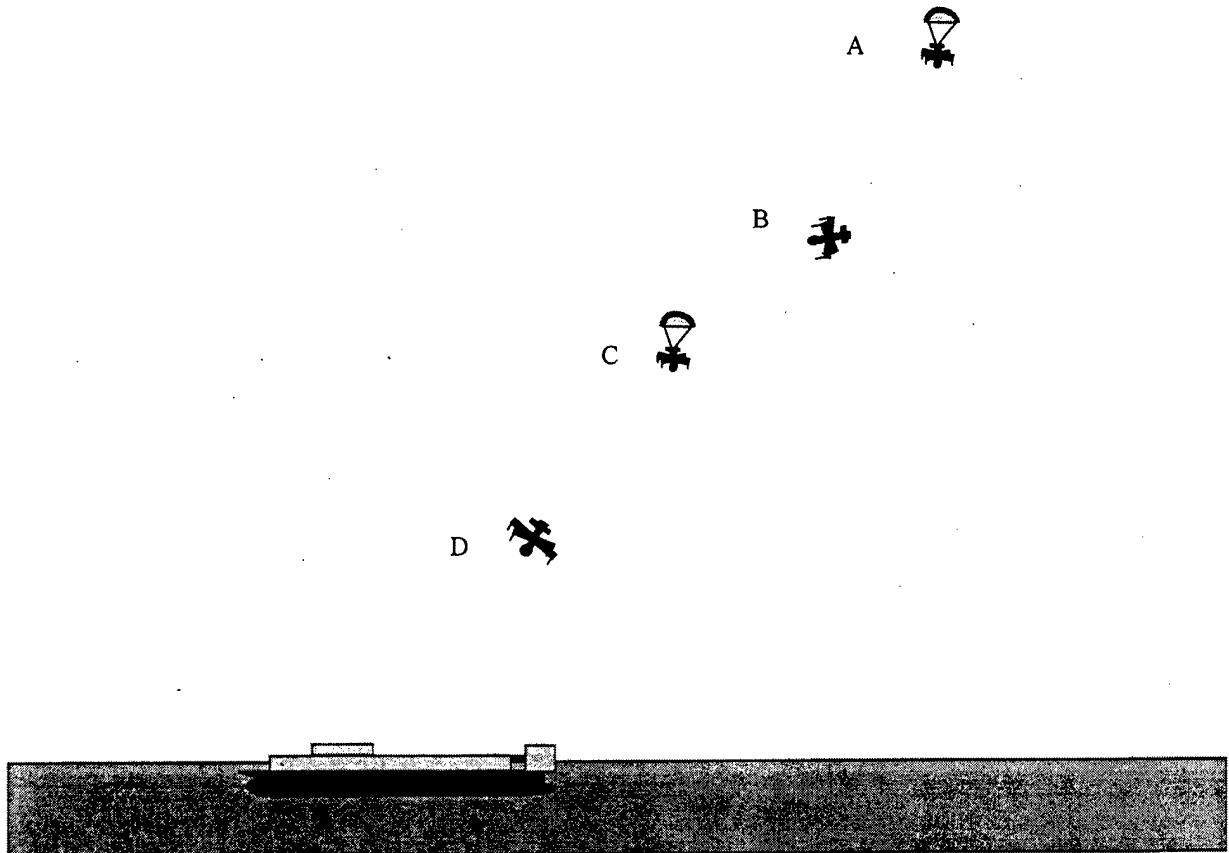
Figure 4. Brilliant Anti-Tank Submunition Profile. Typical BAT profile as it glides in on its target [Ref. 6]. A. Once at altitude the BAT deploys a parachute and looks for the target acoustically. B. Once an acoustic signature is located and the parachute releases and BAT free-falls in the general direction of the target. C. A second parachute deploys while the BAT acoustically pinpoints the target. D. The second parachute releases and the BAT glides in on the target with an infrared seeker.

THIS PAGE INTENTIONALLY LEFT BLANK

III. LAUNCHER DESIGN

A. REQUIREMENTS

In order for the launcher to be a successful weapon system, it needs to provide as much "bang for the buck" and still meet the dimensional requirements of the torpedo tube and stow. Therefore, the launcher, which we will refer to as the SEABAT, can not exceed 21" in diameter and with two launchers per stow, the length can not exceed 123". The weight of the SEABAT fully loaded will be more restricted by buoyancy and stability criteria than the maximum stow capacity of 4600 lbs. Issues of weight restrictions are addressed in section IV.

1. Propulsion

Torpedoes are self-propelled after an initial jettison from the torpedo tube. It would be easier and more cost effective if the SEABAT did not require such a propulsion system but was launched and deployed to the surface with positive buoyancy. In order to determine this, analysis [Ref. 7] was conducted at the Naval Undersea Warfare Center (NUWC) in Newport, Rhode Island to determine the feasibility of ignoring a propulsion system in the SEABAT's design. The computational model, Underwater Vehicle Launch Dynamics Simulation (UVLDS), was run at ten knots, five knots and "bare steerage way" and for each case the initial jettison from the tube was sufficient force to clear the

200m

5 knots

Bare strge ←   ←―――10 knots

100m

0m

200m   100m   0m   100m   200m

200m   ⌐10 knots   5 knots   Bare
                                                          strge

100m

0m
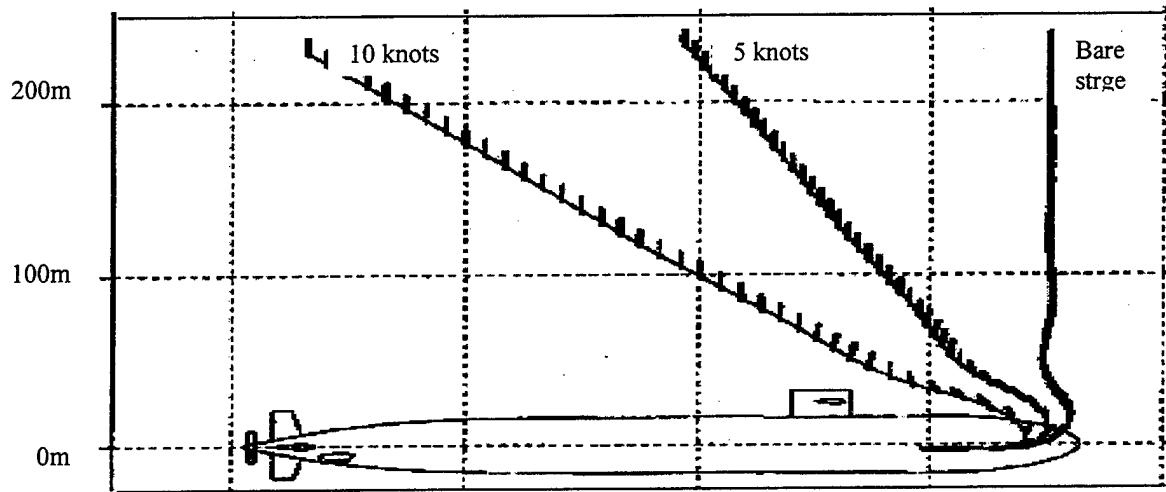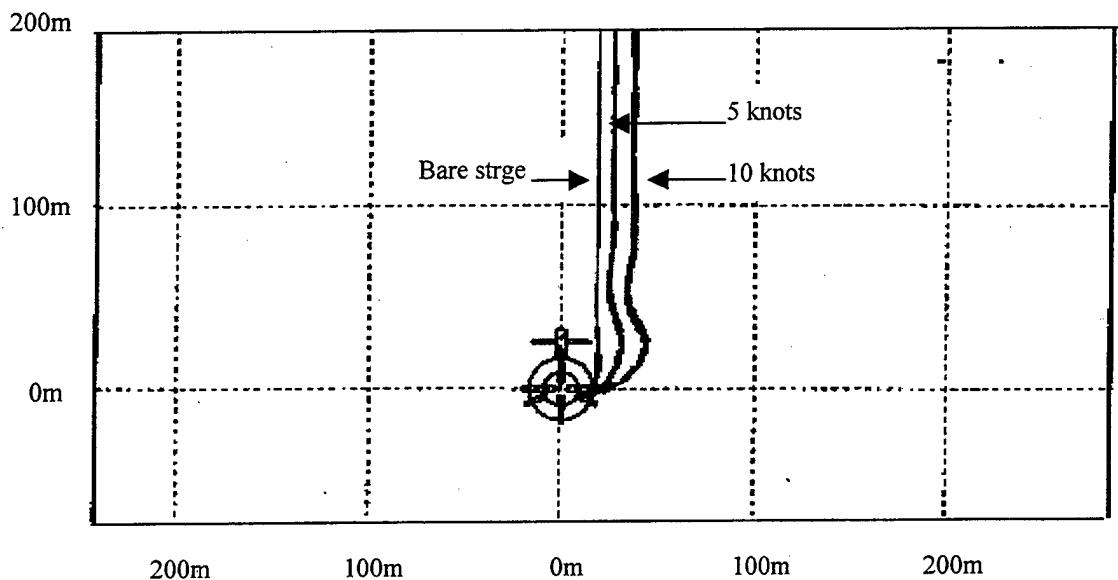
Figure 5. From Ref. [7]. Axial and Elevation View of Torpedo Tube Launch. The top figure is the axial view of the launch profile of the SEABAT at bare steerage way, five knots and ten knots. The bottom figure is the elevation view. The SEABAT has the dimensions of 123" in length and 21" in diameter and is positively buoyant.

SEABAT from the submarine's hull and safely rise to the surface. The successful criteria for launch modeling is to maintain increasing radial clearance from the launch platform at

all time following launch and exit from the submarine. Both the axial and elevation views of the test model clearly show sufficient clearance of the SEABAT from the submarine's hull. The conclusion is that a propulsion system was unnecessary in the design of the SEABAT.

2. Magazine

The magazine will house the missiles, electronics and booster "squibs". Based on the diameter of 21" for the SEABAT and 6" maximum diameter for a missile, five missiles can fit into each SEABAT. The length of the magazine will be 98", six inches for the squib fire and 92" for the missile. The missile will include 48" for the booster, 36" for the BATS and eight inches for the inertial navigation system (INS). Five canisters will house each of the five missiles with the associated electronics fitted between the canisters.
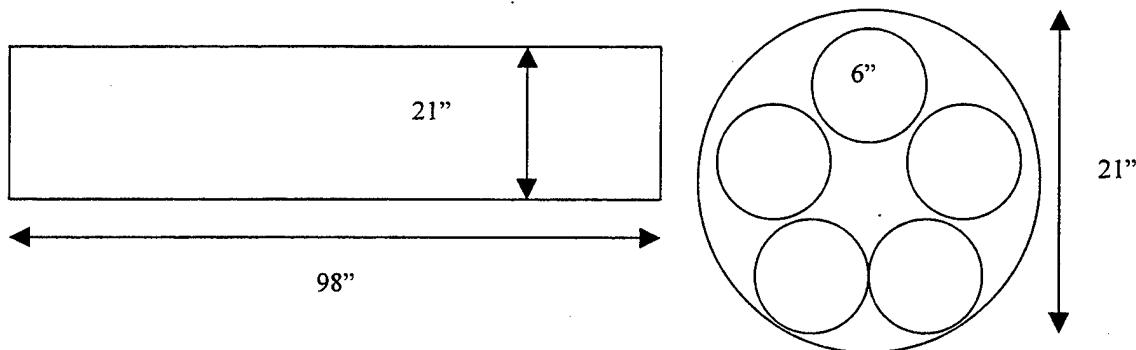
Figure 6. Side and Cross-Section View of the Proposed Magazine. Above is the side and cross-sectional view of the proposed magazine for the weapon system. The body will be 98" long to include a 6" squib fire and 92" of missile. The cylinder will be 21" in diameter with 6" diameter canisters that allow for a five, missile configuration. The electronics will be fitted in between the canisters along the length of the magazine.

3. Hydrodynamics

It is important that the SEABAT glides through the water during ascent with as little drag as possible. This will increase the rise time to the surface and help prevent "tumbling" when jettisoned from the torpedo tube. For this reason, a cap will be designed, similar to that of the Mk48 torpedo, to provide the hydrodynamics necessary for a smooth ascent to the surface and provide watertight integrity for the missiles and electronics housed inside the SEABAT. The cap will measure six inches in length.
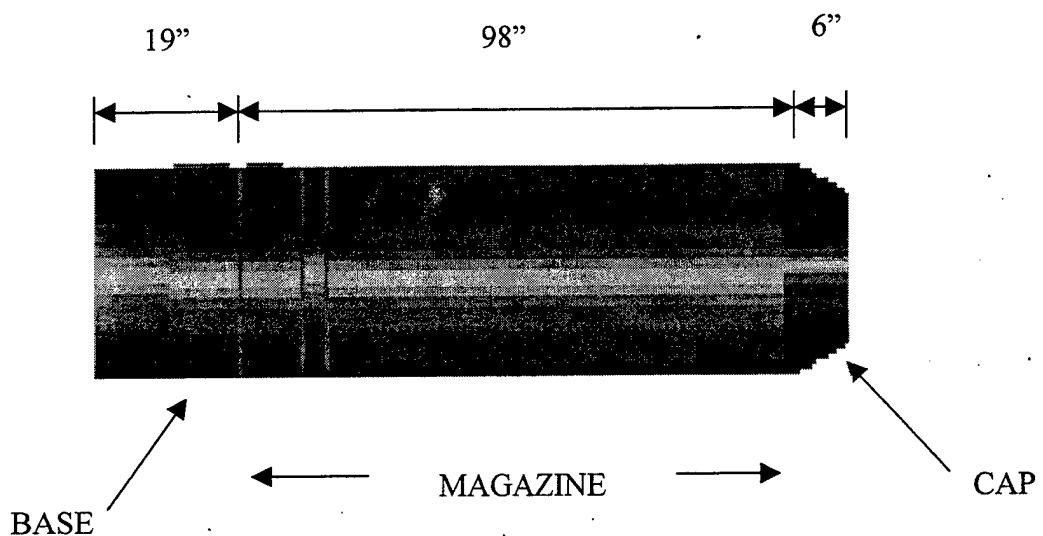
Figure 7. SEABAT. The proposed SEABAT design is 123" in length and 21" in diameter. It includes a 19" base for the anchoring system, a 6" cap for pressure seal and hydrodynamics and 98" of magazine to house the missiles and associated electronics.

4. Anchoring

An anchoring system would be advantageous in securing the SEABAT to a designated location. There would be some movement depending on the water depth and currents, but far less movement than if the SEABAT were free floating. With a length constraint of 123" for the entire SEABAT, there is only 19" left for the anchoring system after the magazine and cap lengths are subtracted. A 1/2" steel cable has a density of 0.11 lbs/ft and provides sufficient tensile strength to anchor the launcher to the bottom. Coastal depths are relatively shallow, therefore, 900 ft of cable (99 lbs) are adequate for deploying and anchoring the SEABAT. A 150 lbs weight will deploy until it reaches the bottom and "digs in" while a winch will control paying out the cable. The winch, cable and anchor will all fit in the bottom 19" of the SEABAT.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. PHYSICAL LIMITATIONS

A. INTRODUCTION

There are limitations in length, diameter and mass of SEABAT that are imposed by the restrictions of the torpedo stow and torpedo tube. These are not the only limitations the SEABAT design must consider. In order to float while tethered and successfully launch missiles, the SEABAT must not violate the basic laws of physics. To float, SEABAT must be positively buoyant at all stages of its lifetime. Buoyancy is the force generated by the displaced volume of a given shape. If the shape is lighter than the volume of the medium it displaced than it will float (positively buoyant) otherwise it will sink (negatively buoyant). The volume SEABAT displaces and the mass of SEABAT at each event are utilized to determine the buoyancy and to ensure SEABAT will not sink. Stability ensures the SEABAT will keep its' magazine face above the waterline for the safe launching of missiles. Stability is a factor of the center of buoyancy (COB) and the center of mass (COM). The COB is the center of the enclosed volume of an object. The COM is the center of the enclosed mass of an object.

B. BUOYANCY

Buoyancy is a measurable force as defined by Archimedes' Principle. It is the product of the volume of an object, density of the displaced medium and gravitational acceleration. The SEABAT is designed to float on the surface while anchored. Therefore, buoyancy is a vital component to the success of the weapon system or else it would sink. The dimensions of the SEABAT are predetermined by the size of the torpedo tube:

Length of SEABAT (L_s) = 123"
Radius of SEABAT (r_s) = 10.5"

The SEABAT is composed of three sections, the cap, the magazine and the base. The cap is a conical shaped lid for hydrodynamic motion through the water during initial deployment of the SEABAT. The magazine houses five missiles, five canisters, five "squib" fires and associated electronics. The base contains the anchor, winch and cable.

The section lengths are:

Length of the cap (L_c) = 6"
Length of the magazine (L_m) = 98"
Length of the base (L_b) = 19"

The volume of the SEABAT can be derived from these dimensions.

Volume of the cap (V_c) = $(2/3)\pi r_s^2 L_c \approx 1380$ in^3	(1)
Volume of the magazine (V_m) = $\pi r_s^2 L_1 \approx 33800$ in^3	(2)
Volume of the base (V_b) = $\pi r_s^2 L_b \approx 6550$ in^3	(3)
Volume of the SEABAT (V_s) = $V_c + V_m + V_b \approx 41700$ in^3	(4)

Density and gravitational acceleration will be assumed to be constant in solving for buoyancy.

Density of seawater (ρ_{sw}) = 1000 Kg/m^3 = .036 lbs/in^3
Density of air (ρ_a) = 1.292 Kg/m^3 = 4.8×10^{-6} lbs/in^3
Gravitational acceleration (g) = 9.81 m/s^2 = 383 in/s^2

Each phase of SEABAT's deployment and launch will have unique buoyancy that will depend on the volume of the SEABAT above water and the volume of SEABAT below water. It is important that during any given event the buoyant force is greater than the mass acceleration of the SEABAT to prevent sinking.

1. Equilibrium Height

The equilibrium height (y_e) of the SEABAT defines the amount of free surface area above the waterline. The equilibrium height is required after each event to accurately

assess the buoyant forces for the duration of the SEABAT's launch and fire events.

Equilibrium height is a factor of volume and mass of the SEABAT. The initial

equilibrium height of 10" was predetermined to define the mass limitations of the

SEABAT.

Equilibrium height (y_e) = 10"
Volume of SEABAT above water $(V_{sa}) = \pi r_s^2(y_e - L_c) + V_c \approx 2760$ in^3 (5)
Volume of SEABAT below water $(V_{sb}) = \pi r_s^2(L_s - y_e) \approx 39000$ in^3 (6)
Buoyancy of SEABAT at equilibrium $(B_{se}) = V_{sb}\rho_{sw}g + V_{sa}\rho_a g \approx 6270$ N   (7)

At launch, the only medium displaced is seawater, therefore, an additional amount of

force was present.

Volume of the SEABAT $(V_s) = V_c + V_m + V_b \approx 41700$ in^3 (8)
Buoyancy of SEABAT at launch $(B_{sl}) = V_s\rho_{sw}g \approx 6710$ N   (9)

The buoyant force at launch is 6714 N, but when equilibrium is achieved the force drops

to 6270 N because seawater and air are displaced. Therefore, the mass of the launcher to

achieve a 10" equilibrium height at launch is:

Mass of SEABAT to achieve y_e = 10" $(m_s) \rightarrow (V_s\rho_{sw})(L_s - y_e)/(L_s) \approx 1390$ lbs   (10)

a. Masses

Now that a maximum weight limit has been established, the masses of the

individual components can be approximated. The following is a list of design masses for

the various components of the SEABAT:

Mass of the cap (m_c) = 20 lbs
Mass of one missile (m_m) = 150 lbs
Mass of one canister (m_{ca}) = 20 lbs
Mass of the anchor (m_a) = 150 lbs
Radius of anchor cable (r_{ac}) = 0.25"
Length of anchor cable (L_{ac}) = 900'
Density of anchor cable (ρ_{ac}) = 0.11 lbs/ft
Mass of the anchor cable $(m_{ac}) = L_{ac}\rho_{ac}$ = 99 lbs
Mass of the winch (m_w) = 21 lbs

Mass of the shell, electronics, etc $(m_{misc}) = m_s - (m_c + m_a + m_{ac} + m_w + 5m_m + 5m_{ca}) = 243$ lbs

The mass will decrease after each event. The following is a list of masses after each event:

SEABAT mass after cap blown $(m_{s2}) = m_s - (m_c) \approx 1360$ lbs $\qquad$ (11)
SEABAT mass after anchor deployed $(m_{s3}) = m_s - (m_c + m_a + m_{ac}) \approx 1110$ lbs $\quad$ (12)
SEABAT mass after 1st missile $(m_{s4}) = m_s - (m_c + m_a + m_{ac} + m_m) \approx 964$ lbs $\qquad$ (13)
SEABAT mass after 2nd missile $(m_{s5}) = m_s - (m_c + m_a + m_{ac} + 2m_m) \approx 814$ lbs $\qquad$ (14)
SEABAT mass after 3rd missile $(m_{s6}) = m_s - (m_c + m_a + m_{ac} + 3m_m) \approx 664$ lbs $\qquad$ (15)
SEABAT mass after 4th missile $(m_{s7}) = m_s - (m_c + m_a + m_{ac} + 4m_m) \approx 514$ lbs $\qquad$ (16)
SEABAT mass after 5th missile $(m_{s8}) = m_s - (m_c + m_a + m_{ac} + 5m_m) \approx 364$ lbs $\qquad$ (17)

b. Volume

Volume of the SEABAT varies after each event. When the cap blows, the top 6" of SEABAT is gone; when the anchor deploys, the bottom 7" of SEABAT floods; and when each missile is fired a canister floods. All of these events facilitate a volume loss. The following canister dimensions and equation are used to calculate volume. "N" is the number of missiles fired and "M" is an integer multiplier that corresponds to the 7" of anchor base being flooded.

Radius of canister $(r_c) = 3$"
Length of canister $(L_{ca}) = 98$"
$V_s = \pi r_s^2 (L_s - L_c - M7") - N\pi r_c^2 L_{ca}$ $\qquad$ (18)

Event	M	N	L_s	V_s (in³)	V_s (m³)
Tube launch	0	0	123"	41,700	0.703
After cap blown	0	0	117"	40,300	0.680
Anchor deployed	1	0	117"	37,900	0.639
After 1st missile	1	1	117"	35,100	0.593
After 2nd missile	1	2	117"	32,400	0.546
After 3rd missile	1	3	117"	29,600	0.499
After 4th missile	1	4	117"	26,800	0.452
After 5th missile	1	5	117"	24,100	0.405

Table 2. Volumes. After each event, the volume that SEABAT displaces must be recomputed due to anchor deployment and tube flooding. "M" is an integer multiplier that corresponds to the 7" of anchor base being flooded (M = 1) or not (M = 0). "N" is an integer multiplier that corresponds to the number of missiles that have been fired.

c. Mass Force

The "mass force" is defined as the buoyant force pushing up on the SEABAT. It is linked to the equilibrium height by a simple ratio of masses and lengths. To determine the "mass force" after each event, assumptions have to be made regarding volumes above and below seawater. For instance, after the cap is blown, the "mass force" will be based on 4" above the water and 113" below the water. This was determined by the absence of the cap (-6") and the initial equilibrium height (10"). Each subsequent event will be calculated under the assumption that "equilibrium height was met prior to the commencement of the next event". The following parameters and equations are used to determine the "mass force" and the corresponding equilibrium height.

Mass of SEABAT = m_s
Mass force = m_f
Length of SEABAT = L_s
Equilibrium height = y_e

$$m_f = (\text{volume below water})\rho_{sw} + (\text{volume above water})\,\rho_a \qquad (19)$$

$$\left(\frac{m_s}{m_f}\right) = \left(\frac{L_s - y_e}{L_s}\right) \qquad (20)$$

Event	M_s (lbs)	L_s	m_f (lbs)	y_e
After cap blown	1360	117"	1410	3.5"
Anchor deployed	1110	117"	1330	17.5"
After 1st missile	964	117"	1070	10.8"
After 2nd missile	814	117"	1100	31.8"
After 3rd missile	664	117"	906	29.3"
After 4th missile	514	117"	934	49.4"
After 5th missile	364	117"	705	56.5"

Table 3. Mass Force and Equilibrium Height. The mass force is used to determine the free surface area of SEABAT above the waterline. It is also referred to as the equilibrium height. The equilibrium height enables calculations to be made based on the amount of air and water displaced by SEABAT. Since the densities of air and water are drastically different, accurate buoyancy forces must be calculated based on equilibrium height.

2. Buoyancy Calculations

The buoyancy after each event will be based on the volume of the SEABAT

above and below the waterline. The following is a list of buoyancy after each event:

Volume of SEABAT above water $(V_{sa}) = \pi r_s^2(y_e)$ (21)
Volume of SEABAT below water $(V_{sb}) = \pi r_s^2(L_s - y_e - L_c - M7") - N\pi r_c^2(L_{ca} - y_e)$(22)
Buoyancy of SEABAT at equilibrium $= V_{sb}\rho_{sw}g + V_{sa}\rho_a g$ (23)

Event	M	N	y_e	Volume above water (in^3)	Volume below water (in^3)	Buoyancy at equilibrium (N)
Tube launch	0	0	10"	2760	39,000	6270
After cap blown	0	0	3.5"	1210	39,100	6300
Anchor deployed	1	0	17.5"	6030	31,900	5130
After 1st missile	1	1	10.8"	3420	31,700	5110
After 2nd missile	1	2	31.8"	9160	25,100	4040
After 3rd missile	1	3	29.3"	7620	22,000	3540
After 4th missile	1	4	49.4"	11,400	15,400	2480
After 5th missile	1	5	56.5"	11,500	12,600	2020

Table 4. Buoyancy at Equilibrium. Buoyancy calculations were made based on the volume of water and air displaced by SEABAT at equilibrium of each event. This force allows for the determination as to SEABAT's ability to float after each event and if so its height out of water.

C. STABILITY

Stability of the SEABAT can be quantified by determining the COB and COM. As long as the COB is above the COM the SEABAT will stay upright. The distance between the COB and COM defines the righting arm. The righting arm determines the angle off-axis that the SEABAT tilts. The SEABAT needs to keep its magazine "face" above water in order to launch, therefore the angle off-axis must be less than 90°. To get an angle off-axis greater than 90°, more than half of the launcher must be above water. Therefore, to ensure stability, it must be shown that all times the COB is above the COM, and the volume of the SEABAT is greater above the waterline than below the waterline.

1. Center of Buoyancy

The COB is located at the center of volume of the enclosed object. The enclosed volume of the SEABAT varies as the base fills and tubes are flooded, thus the COB changes from event to event. The following equations are used to determine the COB at each event as measured up from the base of the SEABAT.

Volume of SEABAT above water $(V_{sa}) = \pi r_s^2 (y_e)$ (24)

Volume of SEABAT below water $(V_{sb}) = \pi r_s^2 (L_s - y_e - L_c - M7") - N\pi r_c^2 (L_{ca} - y_e)$ (25)

Total volume of SEABAT $= V_{sa} + V_{sb} = \pi r_s^2 L_s$ (26)

Center of Buoyancy (COB) $= L_s/2$ (27)

Event	M	N	Volume above water (in^3)	Volume below water (in^3)	L_s	COB
Tube launch	0	0	2760	39,000	121"	60.5"
After cap blown	0	0	1210	39,100	117"	58.5"
Anchor deployed	1	0	6030	31,900	110"	55.0"
After 1st missile	1	1	3420	31,700	102"	51.0"
After 2nd missile	1	2	9160	25,100	99.4"	49.7"
After 3rd missile	1	3	7620	22,000	85.9"	43.0"
After 4th missile	1	4	11,400	15,400	77.8"	38.9"
After 5th missile	1	5	11,500	12,600	69.8"	34.9"

Table 5. Center of Buoyancy. By knowing the volume of SEABAT above and below the waterline, the perceived length (L_s) of SEABAT can be calculated. One half of this length identifies the position along centerline of the COB. The COB must be above the COM in order for SEABAT to be stable and keep the magazine face above water.

2. Center of Mass

To ensure stability, the COM must be below the COB after each event. With one missile left in the SEABAT, the COB is 38.9" and therefore, the COM must be below 38.9". Keeping in mind the bottom 7" of the base is flooded from the deployment of the anchor, the mass of the SEABAT must be greater in the bottom 38.9" than above 38.9" with one missile left.

V. TIMELINE

A. DESCRIPTION

Time is an important factor in determining the success of the SEABAT to engage High Speed Marine Craft (HSMC). The faster the weapon system can be deployed, the less "lead" time is needed for intelligence. The SEABAT will need to stabilize on the surface initially and after each firing to ensure the "face" of the magazine is clear to fire again. Hydrodynamic effects were not factored into the equations for the timeline calculations, however, these effects would provide a damping effect and therefore would not increase the timeline. It is important to understand all of the factors at each stage of deployment that will determine the time constraints of weapon delivery and engagement. The following are descriptions of the phases of deployment and missile launch that the SEABAT will go through.

1. Tube Launch

Initially, the SEABAT will be launched from the submarine's torpedo tube and rise to the surface. Upon broaching the sea surface, SEABAT will oscillate until reaching a predetermined equilibrium height. The ascension velocity, water depth at launch and duration of oscillation at the surface are the contributing factors to the ascension time.

2. Cap Blown

Once SEABAT is stabilized it will blow its cap to display the magazine face. The loss of cap mass, the force to blow the cap and the volume loss will change the equilibrium height thus causing an oscillation. The length of this oscillation will determine the time it takes for SEABAT to stabilize.
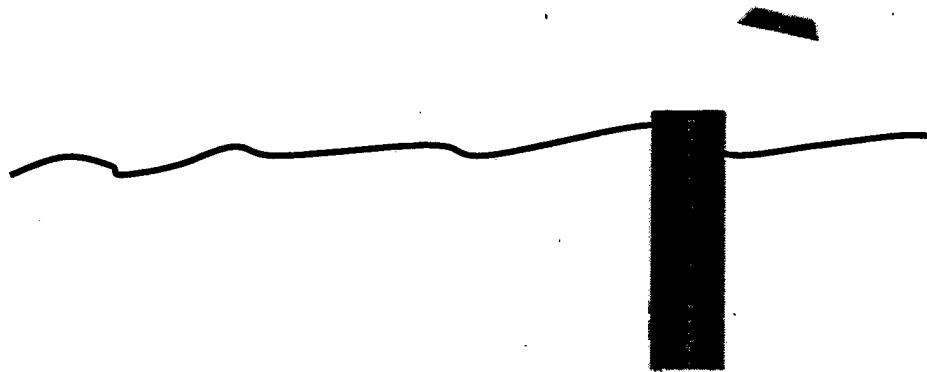
Figure 8. SEABAT Cap Blown. The cap will blow off leaving the magazine face ready to fire.

3. Anchor Deployment

Once SEABAT is stabilized it will deploy its anchor. The bottom seven inches of SEABAT will flood as the anchor drops to the bottom. The resulting loss in mass and volume will change the equilibrium height thus causing an oscillation. The descending velocity, water depth and duration of oscillation are the contributing factors to the deployment time for the anchor.
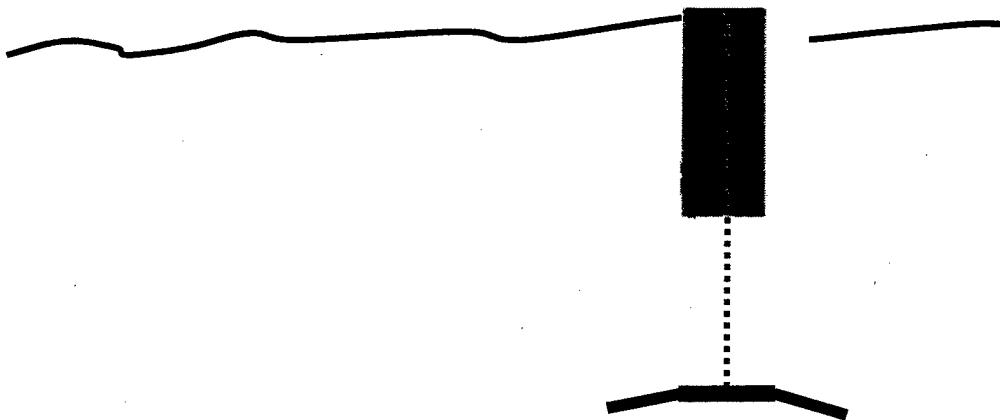
Figure 9. SEABAT Anchor Deployed. The anchor will deploy to help SEABAT maintain a constant position and provide added stability.

4. Missile Launch

Once SEABAT is anchored and the cap has blown it is ready to launch. The downward force of each missile launch will be vented so that only 25% of the force is applied downward on the SEABAT. The venting allows the vacated tubes to flood. After each missile is launched, there will be mass and volume losses that will force a change in the equilibrium height thus causing an oscillation. The downward force of launch and the length of oscillation are the contributing factors to the duration of time between missile launches. At any time, SEABAT can be scuttled remotely via a communications link, otherwise, it will scuttle itself upon completion of the fifth missile launch.

B. CALCULATIONS

Now that the events of the SEABAT's "life" have been defined, it is necessary to calculate the duration of each event. These calculations define the reaction time of the SEABAT and quantify its ability to engage the HSMC. The length of time required to deploy SEABAT and launch its missiles is crucial in determining its effectiveness against HSMC and therefore, must be fast enough such that HSMC can be targeted and engaged within the "kill zone" at a high success rate.

1. Drag

The coefficient of drag (C_D) defines the frictional losses across a given surface. At NUWC, a model is available to simulate various test shapes to determine their drag coefficients. With the cap still on, the shape of SEABAT has a drag coefficient of 1.1. When the cap blows, the drag coefficient changes to 2.0 [Ref. 7]. The effects of skin

friction are important to overall drag, but have been ignored until a composite is identified as the casing for SEABAT.
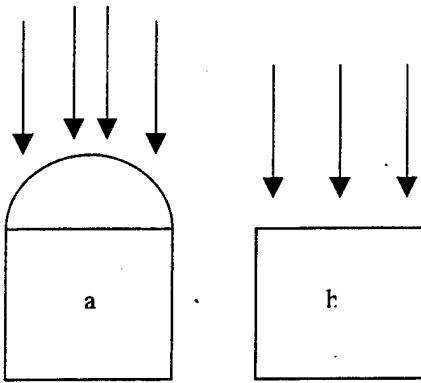

Figure 10. From Ref. [7]. Drag Model. The above shapes were run through the drag model at NUWC with the arrows indicating flow over the given shape. Shape "a" had a drag coefficient of 1.1 and shape "b" had a drag coefficient of 2.0.

2. Velocity

At launch, the SEABAT rises to the surface. When it broaches the surface, the SEABAT oscillates at a certain velocity. These velocities vary from event to event as the drag and buoyancy forces change. The following equation of conservation of energy is used to solve for velocity.

$$(1/2)\rho_{sw}v_s^2C_DA_s = B_s - F_g \rightarrow v_s^2 = 2(B_s - F_g)/(\rho_{sw}C_DA_s) \tag{28}$$

The drag coefficient is 1.1 at launch but is 2.0 for all other events after the cap is blown. The cross sectional area of SEABAT never changes and can be written as:

$$A_s = \pi r_s^2 = 345 \text{ in}^2 = 0.227 \text{ m}^2 \tag{29}$$

The buoyancy of SEABAT (B_s) and the gravitational force (F_g) acting on SEABAT vary with mass and volume.

Event	B_s (N)	F_g (N)	$B_s - F_g$ (N)	v_s (ft/s)
Tube launch	6710	6170	546	6.80
After cap blown	6300	6080	219	3.19
Anchor deployed	5130	4970	164	2.76
After 1st missile	5110	4300	808	6.14
After 2nd missile	4040	3630	407	4.36
After 3rd missile	3540	2960	578	5.20
After 4th missile	2480	2290	185	2.93
After 5th missile	2020	1620	400	4.32

Table 6. Velocities. After each event new calculations were done based on buoyancy and gravitational force. The difference between the buoyant force (B_s) and the force of gravity (F_g) defined the exerted force ($B_s - F_g$) on the SEABAT. An initial velocity of oscillation (v_s) was calculated by utilizing the conservation of energy equation $[(1/2)\rho_{sw}v_s^2 C_D A_s = B_s - F_g]$. The drag ($C_D$), density of seawater ($\rho_{sw}$) and cross-sectional area (A_s) were assumed constant.

3. Spring Constant

When the SEABAT reaches the surface and after each missile launch, oscillations will occur. These oscillations can be quantitatively expressed by finding the spring constant (K) of the SEABAT. By pushing SEABAT down 1" from equilibrium, a resistive force can be felt that is associated with a "perceived mass" (m_{sp}). This mass is used to solve for the spring constant in the following equation.

Mass of SEABAT perceived (m_{sp}) = $V_s \rho_{sw}(L_s - y_e + 1")/(L_s)$ = 1400 lbs   (30)

Spring constant (K) [Ref. 8] = $(m_{sp} - m_s)g/1"$ = 2140 N/m   (31)

Event	V_s (m^3)	L_s (in)	y_e (in)	m_{sp} (lbs)	m_s (lbs)	K (N/m)
Tube launch	0.703	123	10.0	1400	1380	2090
After cap blown	0.680	117	3.50	1430	1360	10700
Anchor deployed	0.633	117	17.5	1180	1110	10600
After 1st missile	0.593	117	10.8	1160	964	34800
After 2nd missile	0.546	117	31.8	860	814	8190
After 3rd missile	0.499	117	29.3	810	664	25400
After 4th missile	0.452	117	49.4	570	514	9290
After 5th missile	0.405	117	56.5	456	364	15900

Table 7. Spring Constants. After each event, new calculations were done based on volume, mass, length, equilibrium height and perceived mass to determine the spring constant of the SEABAT. The spring constant is used to determine settling time for damped oscillations of the SEABAT as it loses mass and volume after each event.

4. Maximum Height

The maximum height (A_o) SEABAT rises above the equilibrium point (y_e) is determined by the kinetic energy (KE) of the SEABAT and the spring constant (K). The following equations are used to calculate kinetic energy and maximum height above equilibrium only taking volume and mass losses into account.

$$\text{Kinetic energy of SEABAT (KE)} = (1/2)m_s v_s^2 \tag{32}$$
$$\text{Maximum height above } y_e, (A_o) = [(2KE)/(K)]^{1/2} \tag{33}$$

Event	KE (Nm)	A_o (in)
Tube launch	1370	45
After cap blown	298	9.0
Anchor deployed	183	7.0
After 1st missile	783	8.0
After 2nd missile	332	11
After 3rd missile	387	7.0
After 4th missile	95	6.0
After 5th missile	147	5.0

Table 8. Kinetic Energy and Maximum Height. The kinetic energy and maximum height above equilibrium are used to determine the settling time of the damped oscillation caused by the loss of mass and volume after each event. The maximum height reaches a peak after the 2nd missile is launched. This is an effect of the loss of mass and volume of the missile firing and the tube flooding. After the 2nd launch, this relationship is at its most extreme and therefore causes the highest oscillation height.

5. Settling Time

The settling time (t_s) defines the duration of oscillation after each event. It is an important calculation in determining the length of time required between firings. The "damped harmonic oscillator" equation provides the tool necessary to calculate settling times. Critical damping would shorten the time duration of oscillation and therefore was ignored to provide a worst case scenario. The following equations are used to calculate frequency and the coefficient of the wave equation for use in the "damped harmonic oscillator" equation.

Oscillating frequency of SEABAT (ω_0) = $(K/m_s)^{1/2}$ (34)

Coefficient of wave equation (b) = $(1/2)\rho_{sw}A_sC_D$ (35)

$$A = A_0\left[\frac{\cos(\omega_0 t_s)}{1+\left(\dfrac{2bA_0\omega_0 t_s}{\pi m_s}\right)}\right] \rightarrow \text{damped harmonic oscillator [Ref. 9]} \quad (36)$$

a. Tube Launch

The SEABAT will be fired from the torpedo tube and ascend to the surface where it will oscillate until stabilization occurs. The velocity of ascent is 2.09 m/s. If SEABAT is launched at periscope depth (50 ft), it will reach the surface in 7.35 seconds. Once at the surface, SEABAT will oscillate until damped to the equilibrium height of 10". An error of $\pm$ 4" from equilibrium will suffice during the first event, however, all subsequent events will meet a $\pm$ 1" criteria.
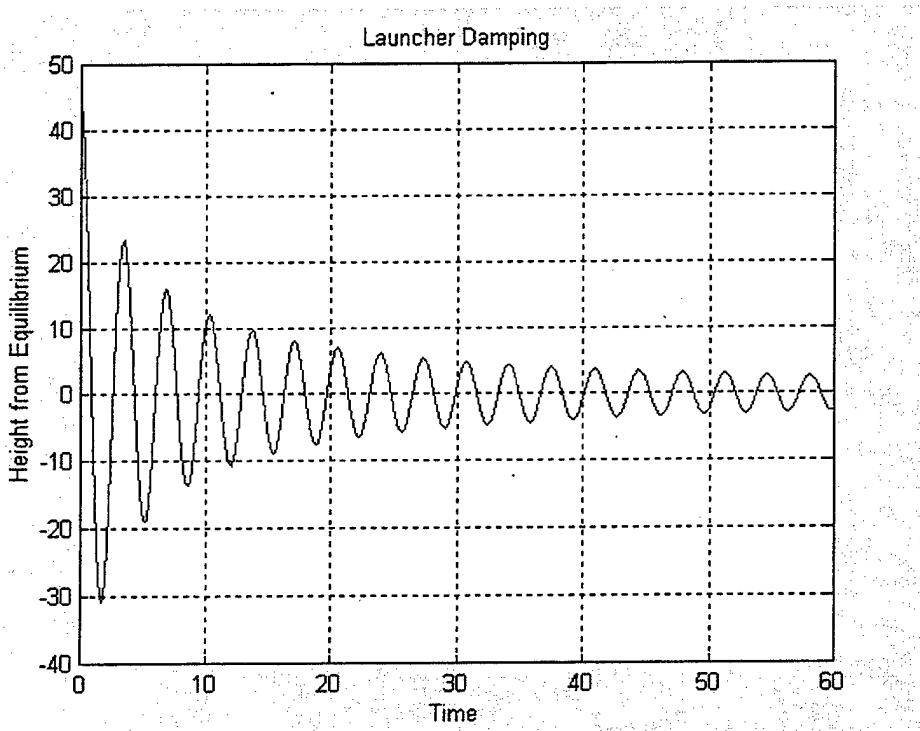
Figure 11. Oscillation at Surface Broach. The time scale is in seconds and the equilibrium height scale is in inches. Upon reaching the surface, SEABAT will oscillate from its maximum height of 45" until equilibrium. The settling time was approximated at 40 seconds when the oscillation was ± 4" from equilibrium. The time duration for launch and stabilization from a 50 ft depth is 48 seconds.

b. Cap Blown

The equilibrium height after the cap is blown is 3.5". At the instant the cap blows, the free surface area above the water line is the difference between the cap height (6") and the initial equilibrium height (10"), which is 4". Due to the relatively small mass loss and therefore low momentum balance, the "face" will reach equilibrium very quickly. Based on these assumptions, the time duration for blowing the cap will be approximated as instantaneous.

c. Anchor Deployment

A 1/2" steel cable will be used as an anchor cable. The deployment of the anchor at a maximum depth of 900' will take the maximum time for setting the anchor. As the anchor falls to the bottom it provides a damping effect on the surface oscillations. Therefore the assumption will be made, that once the anchor is set, the oscillations will have settled. The velocity the anchor descends (v_d) is determined by the following equations and parameters.

$$C_D = 2.0$$
$$\text{Area of anchor } (A_a) = \pi r_a^2 = 345 \text{ in}^2 = 0.227 \text{ m}^2 \tag{37}$$
$$\text{Buoyancy of anchor } (B_a) = 399 \text{ N}$$
$$\text{Buoyancy of cable } (B_c) = 197 \text{ N}$$
$$\text{Gravitational force on anchor } (F_{g1}) = m_s g = 669 \text{ N} \tag{38}$$
$$\text{Gravitational force on cable } (F_{g2}) = m_c g = 442 \text{ N} \tag{39}$$
$$\text{Conservation of Energy} \rightarrow (1/2)\rho_{sw} v_d^2 C_D A_a = B_a + B_c - B_{g1} - B_{g2}$$
$$\rightarrow v_d^2 = 2(B_a + B_c - B_{g1} - B_{g2})/(\rho_{sw} C_D A_a) \rightarrow v_d = 7.37 \text{ ft/s} \tag{40}$$

The time duration to deploy the anchor 900 ft at a velocity of 7.37 ft/s and stabilize the SEABAT is 122 seconds.

d. Missile Launch

When a missile is fired, the downward force of the "squib" fire will be diverted 75% through a vent that will subsequently flood the tube. The "squib" fire exerts 100 psi downward force upon ignition to achieve the desired altitude. The following equations are used to calculate the downward force (F_D) exerted on the SEABAT.

$$F_D = (100 \text{ lbf/in}^2)(4.45 \text{ N/lbf}) = 445 \text{ N/in}^2 \tag{41}$$
$$\text{Cross sectional area of the canister } (A_c) = \pi r_c^2 = 28.3 \text{ in}^2 \tag{42}$$
$$\text{Force exerted on SEABAT} = F_D(A_c) = 12,600 \text{ N} \tag{43}$$

The mass and volume of the SEABAT will change causing an oscillation that is

magnified by 25% of the downward force exerted on the canister bottom. Therefore,

3150 N amplify the oscillation. By using the same damped harmonic oscillator equation,

the settling time can be calculated. The following four figures show the height of the

damped harmonic oscillation of SEABAT after each missile launch over time.
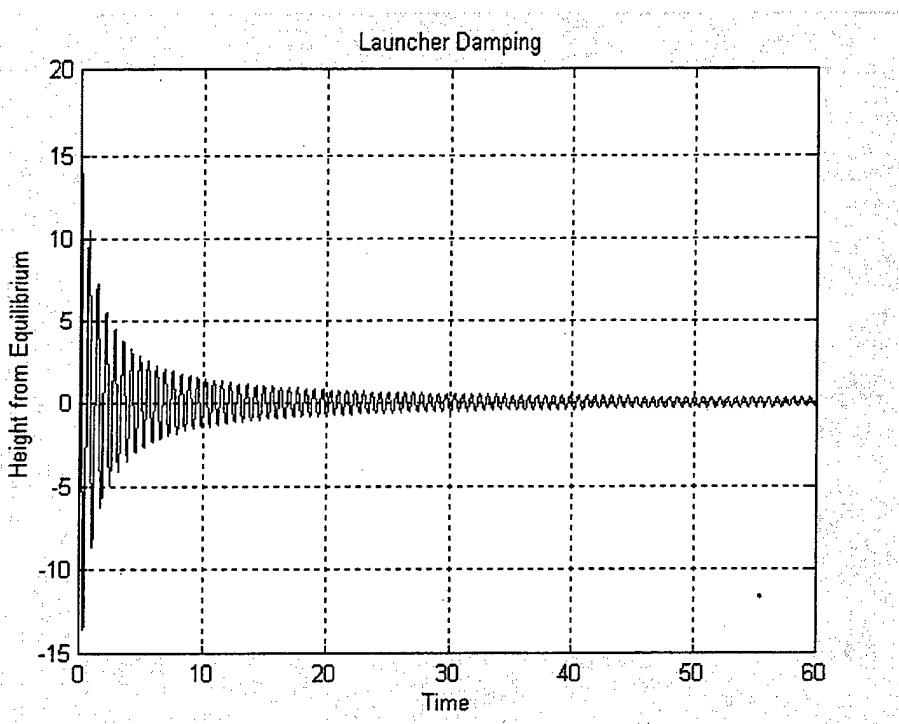

Figure 12. Oscillation After 1st Missile Launch. The time scale is in seconds and the equilibrium height scale is in inches. Once the 1st missile is fired, the SEABAT will oscillate based on mass and volume losses as well as the downward force of the "squib" fire. The maximum height above equilibrium is 18" and it stabilizes to ±1" at 30 seconds. The time duration for 1st missile away and stabilization is 30 seconds.
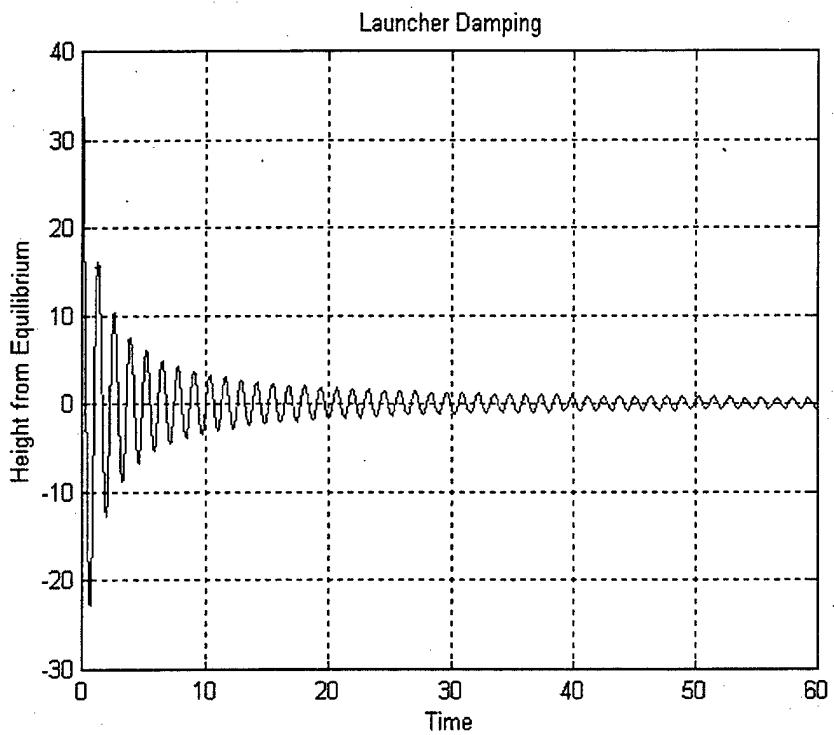
Figure 13. Oscillation After 2nd Missile Launch. The time scale is in seconds and the equilibrium height scale is in inches. Once the 2nd missile is fired, the SEABAT will oscillate based on mass and volume losses as well as the downward force of the "squib" fire. The maximum height above equilibrium is 32" and it stabilizes to ±1" at 20 seconds. The time duration for 2nd missile away and stabilization is 20 seconds.
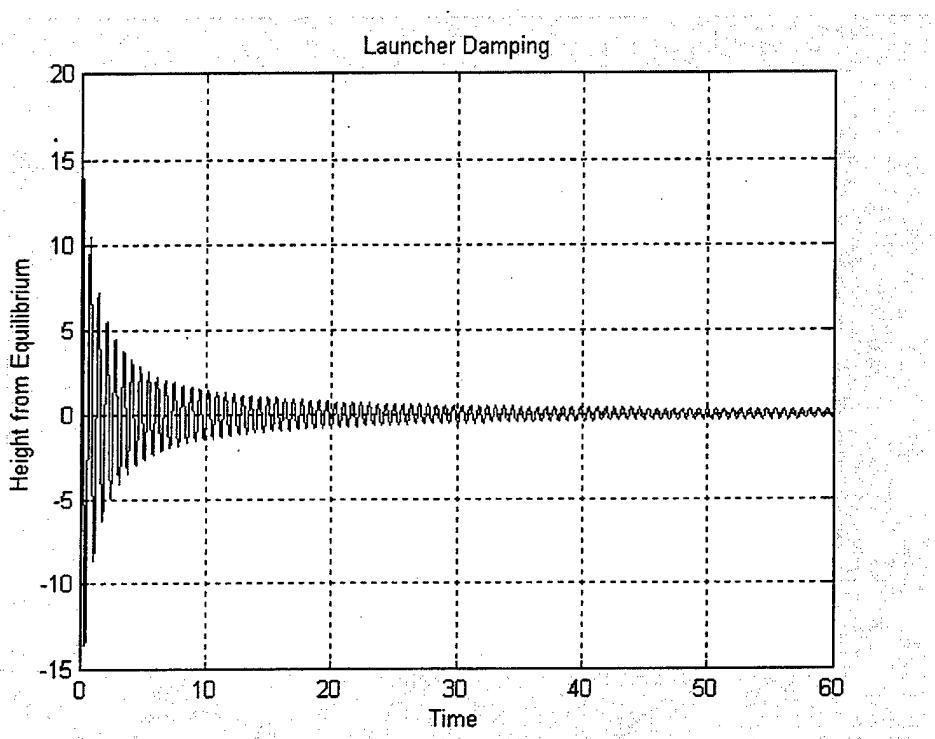
Figure 14. Oscillation After 3rd Missile Launch. The time scale is in seconds and the equilibrium height scale is in inches. Once the 3rd missile is fired, the SEABAT will oscillate based on mass and volume losses as well as the downward force of the "squib" fire. The maximum height above equilibrium is 19" and it stabilizes to ±1" at 30 seconds. The time duration for 3rd missile away and stabilization is 30 seconds.
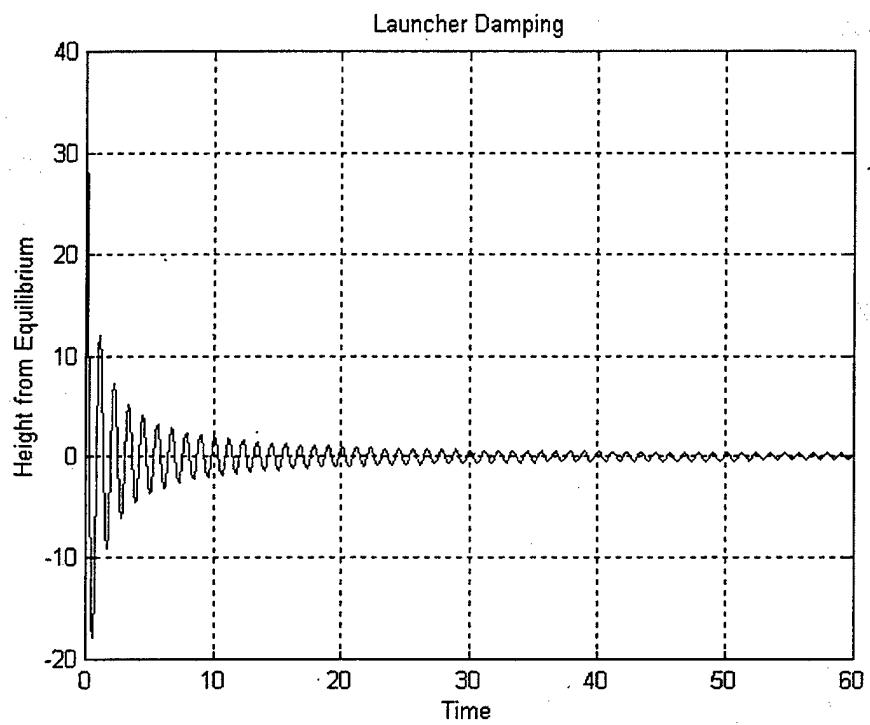
Figure 15. Oscillation After 4th Missile Launch. The time scale is in seconds and the equilibrium height scale is in inches. Once the 4th missile is fired, the SEABAT will oscillate based on mass and volume losses as well as the downward force of the "squib" fire. The maximum height above equilibrium is 33" and it stabilizes to ±1" at 20 seconds. The time duration for 4th missile away and stabilization is 20 seconds. The total time needed to deploy and fire all five missiles is only 270 seconds or four and a half minutes.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSION

The naval threat of the future has become littoral. The vast seagoing fleets of the past are being replaced by smaller, faster and more maneuverable craft. In order to maintain naval superiority in all arenas the United States must adapt to the changing environment. The HSMC threat is real and combating the problem will be difficult. Coastal regions are susceptible to HSMC attacks and infiltrations and friendly assets have a limited availability in a shrinking navy to combat these threats.

The SSN is often in a position as the only asset available in coastal waters to combat the initial wave of HSMC. The SSN needs a weapons capability to engage the HSMC threat. In this thesis, a new weapon system, the SEABAT, is proposed. The SEABAT weapon system design maintains submarine stealth and provides an adequate warhead to slow down and even eliminate a potential HSMC force. Physically, the SEABAT meets the buoyancy and stability requirements to make it a feasible design. The timeline for deployment and launch is under five minutes which gives the SSN ample time to identify and engage the threat. There are no physical limitations to the potential success of SEABAT.

To maximize success, all assets must be utilized to their utmost potential. The SSN is a potent platform that can provide needed support in the littoral regions where HSMC flourish. This thesis has shown that a sub-launched weapon system is feasible for the engagement of HSMC in the littoral environment. The SEABAT design provides insight into the ability of an SSN to combat the HSMC successfully and with a lot of diversity. The SEABAT design proposed in this thesis does meet buoyancy and stability requirements and also enables the SSN to maintain stealth and selectively engage the

threat with a good success rate. In the future, adaptations can be used to allow multiple

platforms to launch and control the SEABAT in a complex littoral environment.

LIST OF REFERENCES

1. Interview with SE4021 Project Team, Naval Postgraduate School, Monterey, CA, and the author, March 1999.

2. Bureau of Naval Personnel. [http://www.bupers.navy.mil/PERS42/PERS42opening.htm]. October 1999.

3. Jane's 1999 Catalogue. [http://www.janes.com/company/catalog99/navalweapon.html]. September 1999.

4. Interview between Scott Mullet, Naval Air Warfare Center, Chinalake, CA, and the author, October 1998.

5. United States Army. [http://www.sarda.army.mil/sarda_zs/saal_zs_public_docs/weapon_systems_handboo k/wsh_photos_/216bat/216bat.html]. October 1999.

6. Interview between Matthew Begert, LtCol, USMC, Precision Guided Weapons Countermeasures Test and Evaluation Directorate, White Sands Missile Range, NM, and the author, January 1999.

7. Interview between John D. Babb, Naval Undersea Warfare Center Newport Division, Newport, RI, and the author, January 1999.

8. Halliday, D., Resnik, R., and Walker, J., *Fundamentals of Physics Extended*, 5th ed., pp. 140-142, John Wiley and Sons Inc., 1997.

9. Marion, J.B., *Classical Dynamics of Particles and Systems*, pp.132-135, Academic Press Inc., 1965.

THIS PAGE INTENTIONALLY LEFT BLANK

BIBLIOGRAPHY

Boas, M.L., *Mathematical Methods in the Physical Sciences*, 2d ed., John Wiley and Sons Inc., 1966.

Bureau of Naval Personnel.
[http://www.bupers.navy.mil/PERS42/PERS42opening.htm]. October 1999.

Fowles, G.R., and Cassiday, G.L., *Analytical Mechanics*, 5th ed., Harcourt Brace and Company, 1993.

Halliday, D., Resnik, R., and Walker, J., *Fundamentals of Physics Extended*, 5th ed., John Wiley and Sons Inc., 1997.

Interview between John D. Babb, Naval Undersea Warfare Center Newport Division, Newport, RI, and the author, January 1999.

Interview between Matthew Begert, LtCol, USMC, Precision Guided Weapons Countermeasures Test and Evaluation Directorate, White Sands Missile Range, NM, and the author, January 1999.

Interview between Scott Mullet, Naval Air Warfare Center, Chinalake, CA, and the author, October 1998.

Interview with SE4021 Project Team, Naval Postgraduate School, Monterey, CA, and the author, March 1999.

Jane's 1999 Catalogue.
[http://www.janes.com/company/catalog99/navalweapon.html]. September 1999.

Marion, J.B., *Classical Dynamics of Particles and Systems*, Academic Press Inc., 1965.

Medwin, H. and Clay, C.S., *Fundamentals of Acoustical Oceanography*, Academic Press 1998.

Polmar, N., *The Ships and Aircraft of the U.S. Fleet*, 14th ed., Naval Institute Press, 1987.

Thornton, S.T., and Rex, A., *Modern Physics for Scientists and Engineers*, Saunders College Publishing, 1993.

Tipler, P.A., *Physics*, 2d ed., v.1, Worth Publishers Inc., 1982

Tipler, P.A., *Physics*, 2d ed., v.2, Worth Publishers Inc., 1982

United States Army.
[http://www.sarda.army.mil/sarda_zs/saal_zs_public_docs/weapon_systems_handbook/w
sh_photos_/216bat/216bat.html]. October 1999.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center..2
    8725 John J. Kingman Rd., STE 0944
    Ft. Belvoir, Virginia 22060-6218

2. Dudley Knox Library...2
    Naval Postgraduate School
    411 Dyer Rd.
    Monterey, California 93943-5101

3. Naval/Mechanical Engineering, Code 34...1
    Naval Postgraduate School
    700 Dyer Road, Bldg 245
    Monterey, California 93943-5100

4. William B. Maier II..1
    Naval Postgraduate School PH/MW
    Monterey, California 93943-5101

5. Xavier K. Maruyama...3
    Naval Postgraduate School PH/MX
    Monterey, California 93943-5101

6. John D. Babb...1
    Naval Undersea Warfare Center Newport Division
    Newport, Rhode Island 02841-1708

7. John L. Lowery...3
    107 South 9th Street
    Benton, Illinois 62812